Report No. CG-D-37-95

# Fire Performance Evaluations of Three A-0 Glazed Window Assemblies

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Final Report
October 1995



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1082 Shennecossett Road
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and

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16. Abstract

Three window assemblies, described herein, were tested in accordance with the standard procedures outlined in IMO Res. A.517(13) "Fire Test Procedures for 'A', 'B' and 'F' Class Divisions." The assemblies were exposed for a minimum 60-minute fire exposure without allowing excessive temperature rise or passage of flame. Since the integrity of the window assemblies were maintained during the entire exposure period, the assemblies each met the requirements for a class A-0 window assembly. At the conclusion of the fire exposure period, each assembly was subjected to the hose stream test as outlined in ASTM E 119-83, "Standard Test Methods of Fire Tests of Building Construction and Materials." Each of the three assemblies met the requirements for the hose stream by maintaining their integrity and not forming through openings during the hose stream test. The primary purpose of performing these tests was to determine the radiative heat flux and temperature measurements on the surface of the bulkhead when subjected to fire conditions. Peak heat flux recorded from the unexposed surface of the assemblies was approximately 75 $kW/m^2$ with cumulative fluxes at 60 minutes of approximately 150 $MJ/m^2$. Indicated surface temperatures on the panes approached 800$^{o}$ C, while the steel framework showed surface temperatures of approximately 600$^{o}$ C.

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# METRIC CONVERSION FACTORS

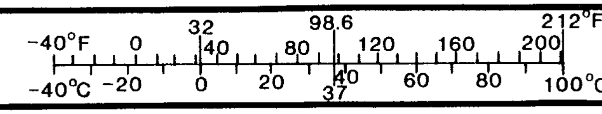
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (WEIGHT)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (EXACT)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly).


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (WEIGHT)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 0.125 | cups | c |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (EXACT)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## 1. INTRODUCTION

This report describes the testing and analysis of three window assemblies, and includes descriptions of the test procedures followed, the assembly tested and the results obtained. The results presented apply only to the material tested, in the manner tested and not to any similar materials or material combinations.

The IMO Res. A.517 (13) "Fire Test Procedures for 'A', 'B' and 'F' Class Divisions" is intended to evaluate the duration for which the described assembly will contain a fire, or retain its structural integrity, or display both properties dependent upon the type of assembly involved during a predetermined fire test exposure.

The test exposes a nonload bearing, vertical glazed element to a standard fire exposure controlled to achieve specified temperatures and pressures throughout a given time period. Points on the standard time/temperature curve are shown in Table 1.1 and are used to control the fire exposure.

**TABLE 1.1 POINTS ON THE TIME/TEMPERATURE CURVE**

| TIME | TEMPERATURE |
|---|---|
| 0:00 minutes | 20°C (68°F) |
| 05:00 minutes | 576°C (1069°F) |
| 10:00 minutes | 679°C (1254°F) |
| 15:00 minutes | 738°C (1360°F) |
| 30:00 minutes | 841°C (1546°F) |
| 60:00 minutes | 945°C (1733°F) |

IMO Res. A.517 (13) is designed to determine the thermal endurance of several classes of decks and bulkheads. The current revision of this procedure does not specifically address window requirements. Notwithstanding, the procedures and acceptance criteria have been applied similar to an "A" class door. Temperature measurements are to be recorded on the unexposed surface of the door. The duration of the test is a minimum of 60 minutes for an "A" class division, with the rise of temperature limited for the stated time period. Observations and criteria are applied for the structural integrity, smoke or hot gas penetration (cotton pad test), and maximum deflections.

This procedure measures the assembly's response to exposure in terms of the transmission of heat and hot gases through the assembly. The insulating value of the specimen should be such that the average temperature reading of the thermocouples on the unexposed surface will not rise more than 139°C above the initial temperature, nor will the temperature at any one point on the surface, including any joint, rise more than 180°C above the initial temperature, during the time specified. These temperature rise requirements should not be exceeded during the time according to the rating desired as follows:

| | |
|---|---|
| "A-60" standard | 60 minutes |
| "A-30" standard | 30 minutes |
| "A-15" standard | 15 minutes |
| "A-0" standard | 0 minutes |

Heat flux (HF) measurements were performed to determine the levels of radiation coming through or from the assembly during the fire exposure. The procedures for the heat flux and temperature measurement are presented in Thermal Radiation From Marine Bulkheads, SwRI report 01-4580, July 1993. Furnace pressure measurements are required to assure that the test specimen maintains a positive pressure with respect to ambient over the upper two-thirds of the assembly. In addition to the test requirements of the IMO procedure, a hose stream test was conducted on each assembly at the end of the fire endurance test in accordance with ASTM E 119-83, Standard Test Methods for Fire Tests of Building Construction and Materials.

## 2. TEST PROCEDURE

SwRI's vertical furnace is capable of exposing a maximum test specimen of 3.8 x 3.8 m (12.5 x 12.5 ft). The 0.76-m (30-in.) deep furnace is equipped with nine premixed air/natural gas burners symmetrically placed across the back wall and controlled by a variable air-gas ratio regulator. Windows are located on both sides of the furnace to allow observation of the surface exposed to the flame.

The conduct of the fire test was controlled according to the standard time/temperature curve, as indicated by the average temperature obtained from the readings of five thermocouples symmetrically located across the face of the specimen 100 mm (4 in.) away (identified as Tf in figures). The thermocouples consisted of a bare bead supported by a ceramic insulator and steel tube such that the bead extended 25 mm (1 in.) from the end of the insulator. The furnace temperature

during a test was controlled such that the area under the average time/temperature curve is within ±15 percent during the first 10 minutes of the test, within ±10 percent of the corresponding area under the standard time/temperature curve during the first half hour, and within ±5 percent for any period after the first half hour. At any time after the first 10 minutes the mean furnace temperature should not differ from the standard curve by more than ±100°C.

Temperatures of unexposed surfaces were measured with 0.5 mm (0.02 in.), Type K (Chromel-Alumel) thermocouples (identified as Ts in figures), brazed to a copper disc 12 mm in diameter and 0.2 mm in thickness. The disc was covered with a 30 x 30 x 2-mm pad having a density of 900 ±10 $kg/m^3$. The pads were attached firmly to the surface. For the nine thermocouples on the glass surface, the bond was formed using a sodium silica 40 solution adhesive thickened slightly with Syloid 244FP powder. The two thermocouples fastened to the mullions were held in place with small clips impaled on steel weld pins adjacent to the pad. Temperature readings were taken at appropriate locations on the unexposed surface and monitored continuously throughout the test. Thermocouple locations are shown in Figure A.1 of Appendix A.

Heat flux measurements were accomplished with transducers of the Schmidt-Boelter type from Medtherm Corporation. Five transducers were located approximately 1.5 m from the surface of the bulkhead (identified as Rad in figures). Three had a view angle of 30° (total heat flux), while the other two had a view angle of 60° (one total heat flux, the other radiative heat flux). Each transducer had an internal body thermocouple to record the water cooling history during the test (identified as Tr in the figures). The arrangement and procedures are further discussed in Thermal Radiation From Marine Bulkheads, SwRI report 01-4580.

Briefly, a total of five heat flux transducers were used in the tests. Three were 30° circular view total heat flux transducers viewing the upper, middle, and lower third of the bulkhead respectively (labeled Rad #1, #2, and #5). The size of the panes was such that these three viewed only the panes and did not include the steel framework in their view. The other two were 60° view transducers viewing the middle of the bulkhead (labeled Rad #3, and #4). Rad #3 was also a total heat flux transducer, while Rad #4 was a radiation pyrometer with a sapphire window. All of the transducers were calibrated to indicate incident heat flux. The layout of the transducers and other information can be found in Figure A-2, Appendix A. Calibration information is presented in Appendix B.

After the 60-minute fire endurance test, the assembly was subjected to the impact, erosion and cooling effects of a hose stream directed first at the middle and then at all parts of the exposed face, changes in direction being made slowly. The stream was delivered through a 64-mm (2.5-in.) hose discharging through a National Standard Playpipe of corresponding size equipped with a 29-mm (1-1/8 in.) discharge tip of the standard-taper smooth-bore pattern without shoulder at the orifice. The water pressure for a 1-hour test was 207 kPa (30 psi) for a duration of 1 minute per 9.3 $m^2$ (100 $ft^2$) exposed area and was located 20 feet from the center of the exposed surface of the test sample.

## 3. TEST ASSEMBLY

Each of the three window bulkhead assemblies consisted of a framework of 16 gage mild steel; the construction was typical of commercial window framework. The window panes consisted of Firelite, a clear ceramic material distributed by Technical Glass Products, Kirkland Washington. A total of nine panes were used in each assembly. The panes were installed in the framework and held in place with glass stops on the unexposed face. The size distribution of the nine panes can be found in the Figure A.3, Appendix A. A strip of closed cell PVC tape (Norton 990) 3 mm thick x 10 mm wide was placed between the pane and the metal framework on both sides of the pane. The overall dimensions of the window bulkhead were 2489 x 1956 mm high (98 x 77 in. high). The bulkhead was installed in one of SwRI's test frames. Photographs of the assembly can be found in Appendix C, Figures C.1 thru C.5.

Eleven thermocouples were placed on the unexposed surface of the window assembly. The pads were adhered to the glass using a sodium silica compound previously mentioned at the locations shown in Appendix A. Two of the eleven thermocouples were mechanically fastened to the steel mullions.

The test frame was then placed on SwRI's Vertical Furnace. The bulkhead/window assembly was then exposed to the heating conditions prescribed in the standard for a 1-hour period. The furnace pressure was continuously recorded at the three-fourths height of the bulkhead for each test.

## 4. TEST RESULTS AND DISCUSSION

### Test 1

The first bulkhead test was conducted on 12 January, 1993. A final check of the instrumentation and equipment was completed. The burners were ignited at 13:53 p.m. to begin the fire exposure period. The ambient temperature at the beginning of the test was 25°C. Observations recorded during this test are presented in Table 4.1.

**TABLE 4.1 TEST 1 OBSERVATIONS**

| TIME (minute:second) | OBSERVATION |
|---|---|
| 00:27 | Water condensation was observed |
| 04:00 | Mid-span of the frame bowed towards the furnace approximately 25 mm (1 in.) |
| 05:55 | Light flaming observed on the exposed face of the assembly from the painted metal surfaces; the bow has increased approximately 38 mm (1.5 in.) |
| 07:30 | PVC tape charring at the lower left |
| 09:22 | Smoke from the tape continues to increase |
| 11:33 | Ts11 intermittently shorting |
| 16:33 | Ts11 intermittently shorting |
| 17:00 | Rad #1 has moved out of position, indicating low heat flux |
| 19:00 | Frame bow approximately the same |
| 25:30 | Smoke evolving from tape has ceased |
| 26:00 | Due to extreme temperatures, Ts5 shorted |
| 30:00 | Window panes heard "rattling" due to loose fit from the loss of tape |
| 31:17 | Ts11 intermittently shorting |
| 36:00 | Due to extreme temperatures, Ts6 shorted |
| 42:00 | Due to extreme temperatures, Ts3 shorted |
| 46:00 | Ts11 continues to short |
| 52:00 | Due to extreme temperatures, Ts4 shorted |
| 60:00 | END OF TEST |

The test was continued to 60 minutes, after which the assembly and test frame were removed from the furnace to perform the hose stream test. The pressure of the water hose stream was set and the distance to the bulkhead checked. The test was performed for 31 seconds with the stream continuously moving over the surface of the exposed bulkhead area. None of the panes experienced cracking or other signs of breakage.

Peak heat flux at 60 minutes was approximately 75 $kW/m^2$. It is interesting to note that the total 30° heat flux transducers were several percentages higher than the total 60° HF transducer which also viewed the cooler steel frame. The exception to this was Rad #1 which apparently moved out of position during the test at 17 minutes.

Due to the range of the heat flux readings, the cumulative flux was calculated based on the highest indicating heat flux transducer, in this case Rad #5. This varies slightly from the previous reference (Thermal Radiation From Marine Bulkheads, 1993) where the cumulative flux was calculated during those tests based on the average flux of Rad #1, #2, #3, and #5. The total cumulative heat flux (for Rad #5) at 60 minutes was approximately 155 $MJ/m^2$. Rad #4 was lower than the others, consistent with the usage of the sapphire window. Heat flux information is further discussed later. Indicated surface temperatures on the panes approached 800°C, with the indicated temperature on the steel frame being approximately 600°C. Plots of the furnace and surface temperature, heat flux and other information can be found in Appendix D, Figures D1. thru D.5.

**Test 2**

The second bulkhead test was conducted on 13 January, 1993. A final check of the instrumentation and equipment was completed. The burners were ignited at 11:30 a.m. to begin the fire exposure period. The ambient temperature at the beginning of the test was 19°C. Observations recorded during this test are presented in Table 4.2.

The test was continued to 60 minutes, after which the assembly and test frame were removed from the furnace to perform the hose stream test. The pressure of the water hose stream was set and the distance to the bulkhead checked. The test was performed for 31 seconds with the stream continuously moving over the surface of the exposed bulkhead area. None of the panes experienced cracking or other signs of breakage.

**TABLE 4.2 TEST 2 OBSERVATIONS**

| TIME (minute:second) | OBSERVATION |
|---|---|
| 00:26 | Water condensation was observed |
| 05:00 | PVC tape flaming, light smoke evolving on the unexposed surface |
| 12:00 | Paint on metal frame discoloring |
| 21:00 | Frame bowed approximately 25 mm (1 in.) toward furnace |
| 36:00 | Glass panes began to rattle |
| 23:00 | Ts9 detached from surface |
| 26:00 | Ts5 detached from surface |
| 27:50 | Ts3 detached from surface |
| 32:00 | Ts6 detached from surface |
| 32:50 | Ts7 detached from surface |
| 58:80 | Ts1 detached from surface |
| 60:00 | END OF TEST |

Those surface thermocouples which detached from the surface during the test (Ts9, 5, 3, 6, 7, and 1) can be seen in the temperature plot in Appendix D, Figure D.8. Peak heat flux at 60 minutes was 69 kW/m$^2$, with the total cumulative heat flux (for Rad #5) at 60 minutes of 149 MJ/m$^2$. The cumulative heat flux curve was based again on Rad #5, although Rad #2 was very close in magnitude through the test. Rad #3 was again lower than the 30° total heat flux transducers. A subtle shift in the curve for Rad #1 again suggested that it moved out of place, though not as severe as the first test. Heat flux information is further discussed later. Indicated surface temperature on the panes approached 800°C, with the indicated temperature on the steel frame being approximately 600°C, as in Test 1. Test data can be found in Appendix D, Figures D.6 thru D.10.

**Test 3**

The third bulkhead test was also conducted on 13 January, 1993. A final check of the instrumentation and equipment was completed. The burners were ignited at 16:06 p.m. to begin the fire exposure period. The ambient temperature at the beginning of the test was 27°C. Observations recorded during this test are presented in Table 4.3.

TABLE 4.3 TEST 3 OBSERVATIONS

| TIME (minute:second) | OBSERVATION |
|---|---|
| 00:42 | Water condensation was observed |
| 02:58 | Light smoke at the top of the assembly seen; frame bowed approximately 25 mm (1 in.) |
| 04:20 | Light flaming on exposed face |
| 05:00 | Some adhesive for thermocouple pads observed changing white in color |
| 06:30 | Smoke from the tape |
| 21:00 | Rattle heard from panes |
| 41:50 | Ts9 detached from surface |
| 60:00 | END OF TEST |

The test was continued to 60 minutes, after which the assembly and test frame were removed from the furnace to perform the hose stream test. The pressure of the water hose stream was set and the distance to the bulkhead checked. The test was performed for slightly longer than the required 31 seconds with the stream continuously moving over the surface of the exposed bulkhead area. None of the panes experienced cracking or other signs of breakage at the 31 second mark, although the middle pane did crack within a few seconds afterwards on subsequent passes of the hose stream.

Peak heat flux at 60 minutes was 73 $kW/m^2$, with the total cumulative heat flux (for Rad #2) at 60 minutes of 156 $MJ/m^2$. This time the cumulative was based on Rad #2 which was slightly higher than Rad #1 and #5. Again, Rad #3 was lower than the 30° transducers due to the added view including the cooler steel. Rad #4 was the lowest, as expected, due to the sapphire window and the wider view. Heat flux information is further discussed later. Indicated surface temperatures on the panes approached 800°C, with the indicated temperature on the steel frame being approximately 600°C, as in Tests 1 and 2. Plots of the surface heat flux and temperatures are given in Appendix D, Figures D.11 thru D.15.

Table 4.4 summarizes the peak heat flux and integrated radiated heat flux recorded up to 60 minutes for each of the total flux transducers during the three tests. From the geometry, Rad #1, #2, and #5 viewed similar areas, thus the recorded fluxes and integrated fluxes should be similar. This is the case except for Rad #1 during test 1 and, to a less extent, test 2, where it is probable that the transducer moved out of position. Rad #3 viewed a larger area which included the cooler steel

framework, and those fluxes and integrated, or cumulative, radiated energy at 60 minutes were approximately 10 to 15 percent lower than the others.

**TABLE 4.4 HEAT FLUX SUMMARY**

| Test | Rad # | Peak HF @ 60 Min (kW/m$^2$) | Total Radiated Energy @ 60 Min (MJ/m$^2$) |
|---|---|---|---|
| 1 | 1 | 44.9 | 106.7 |
| | 2 | 70.9 | 150.0 |
| | 3 | 63.3 | 131.7 |
| | 5 | 74.9 | 155.1 |
| 2 | 1 | 63.0 | 137.8 |
| | 2 | 69.0 | 148.3 |
| | 3 | 62.1 | 131.8 |
| | 5 | 69.3 | 148.9 |
| 3 | 1 | 65.7 | 148.3 |
| | 2 | 72.9 | 155.7 |
| | 3 | 63.8 | 136.5 |
| | 5 | 69.2 | 150.0 |

Although the surface thermocouples were included for consistency with similar tests, it should be noted that the thermocouple did not necessarily record an accurate surface temperature. This is due to the fact that the thermocouple was receiving heat energy from both the panes and the furnace being radiated through the glass and being absorbed on the surface of the copper disk.

## 5. CONCLUSIONS

Three window assemblies, described herein, were tested in accordance with the standard procedures outlined in IMO Res. A.517 (13) "Fire Test Procedures for 'A', 'B' and 'F' Class Divisions." The assemblies were exposed for a minimum 60-minute fire exposure without allowing excessive temperature rise or passage of flame. Since the integrity of the window assemblies were maintained during the entire exposure period, the assemblies each met the requirements for a class A-0

window assembly. At the conclusion of the fire exposure period, each assembly was subjected to the hose stream test as outlined in ASTM E 119-83. Each of the three assemblies met the requirements for the hose stream by maintaining their integrity and not forming through openings during the hose stream test period. The primary purpose of performing these tests was to determine the radiative heat flux and temperature measurements on the surface of the bulkhead when subjected to fire conditions. Peak heat fluxes recorded from the unexposed surface of the assemblies were approximately 69 to 75 $kW/m^2$ with cumulative fluxes at 60 minutes of approximately 150 $MJ/m^2$. Indicated surface temperatures on the panes approached 800°C, while the steel framework showed surface temperatures of approximately 600°C.

# APPENDIX A

## Drawings and Materials Information

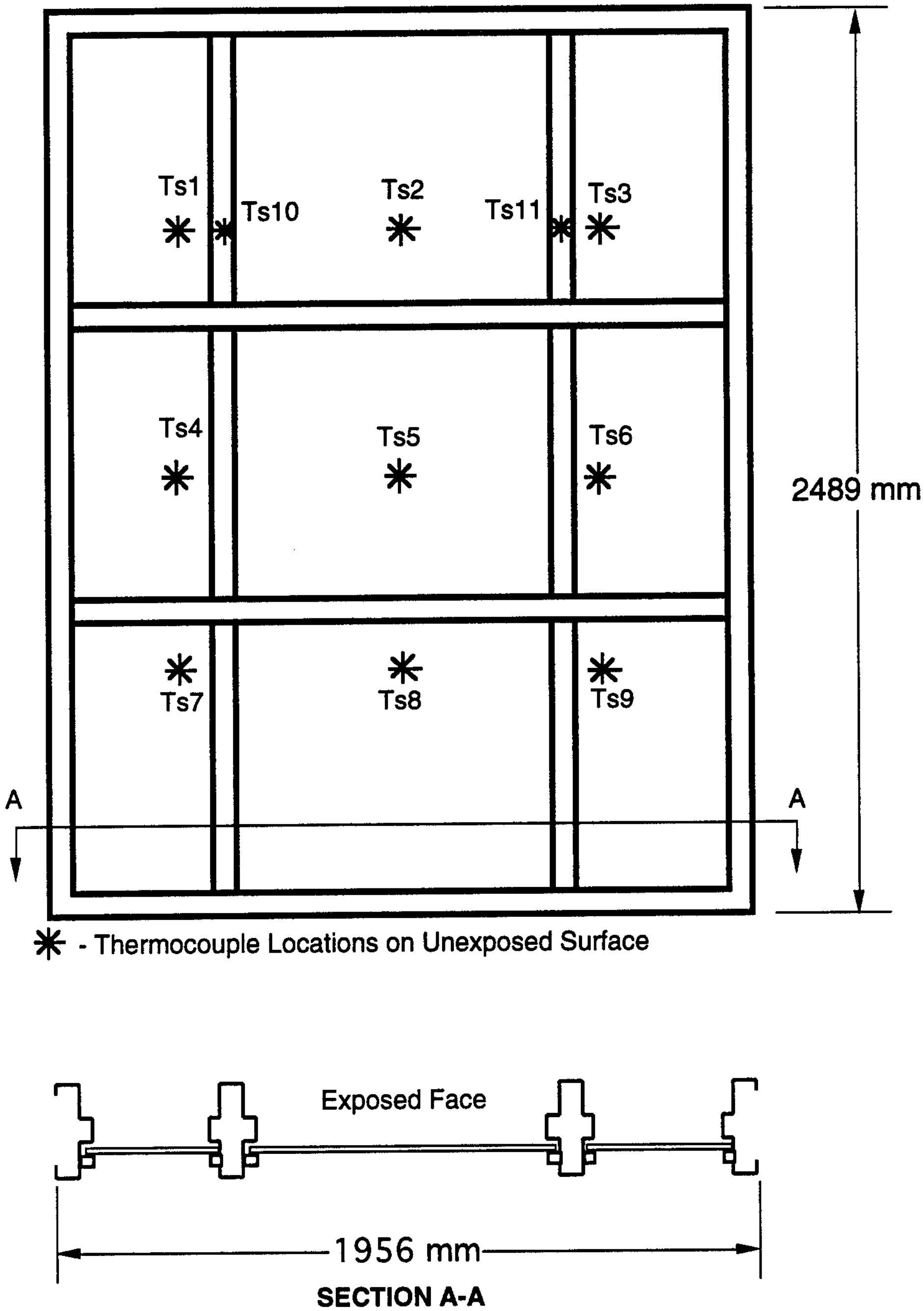
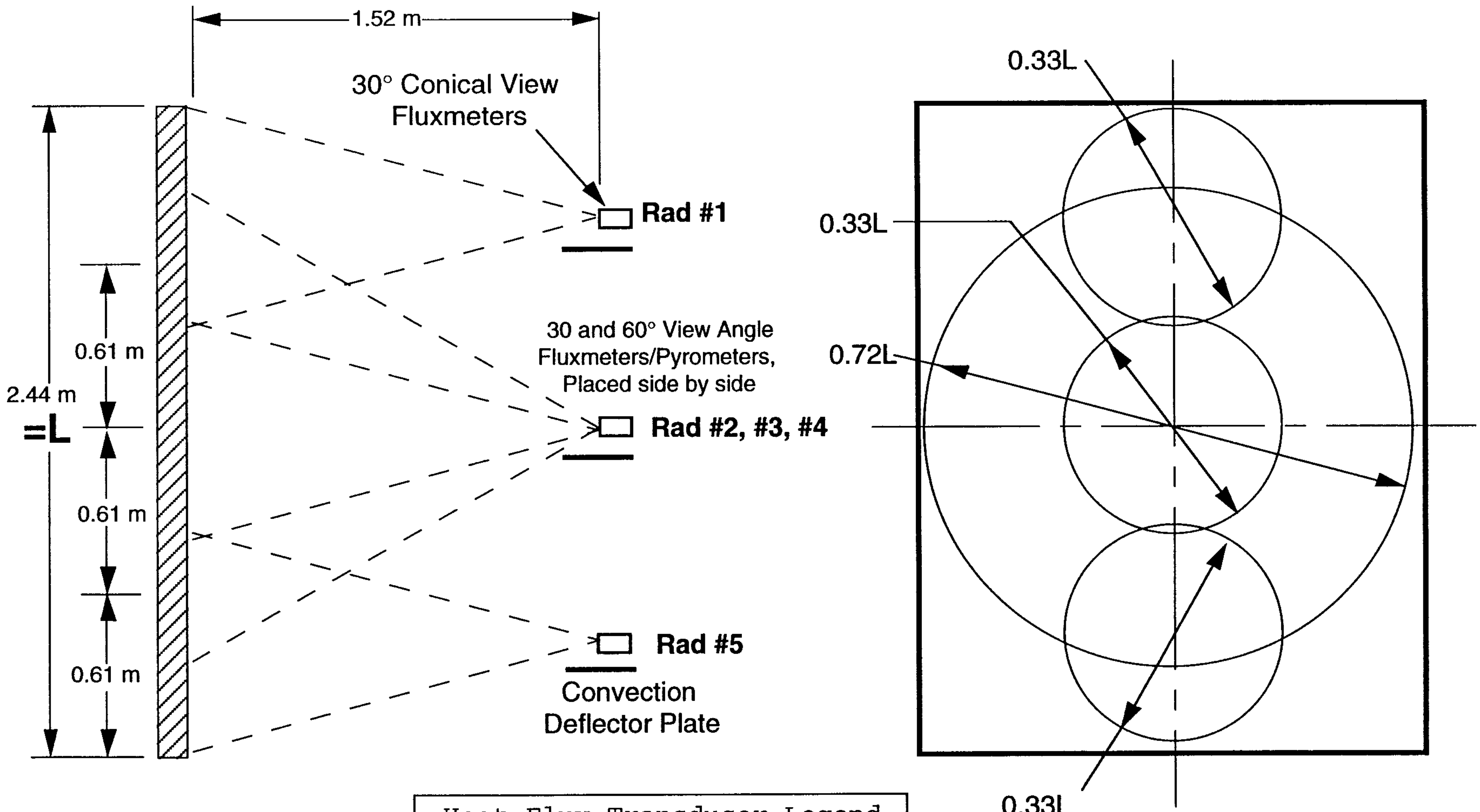



**Figure A.1 Bulkhead Construction, with Surface Thermocouple Locations (Ts1-11)**




Heat Flux Transducer Legend

| No. | View Angle | Type |
|---|---|---|
| Rad #1 | 30° | Total |
| Rad #2 | 30° | Total |
| Rad #3 | 60° | Total |
| Rad #4 | 60° | Radiative |
| Rad #5 | 30° | Total |

**Figure A.2 Heat Flux Transducer Locations with Respect to Bulkhead**

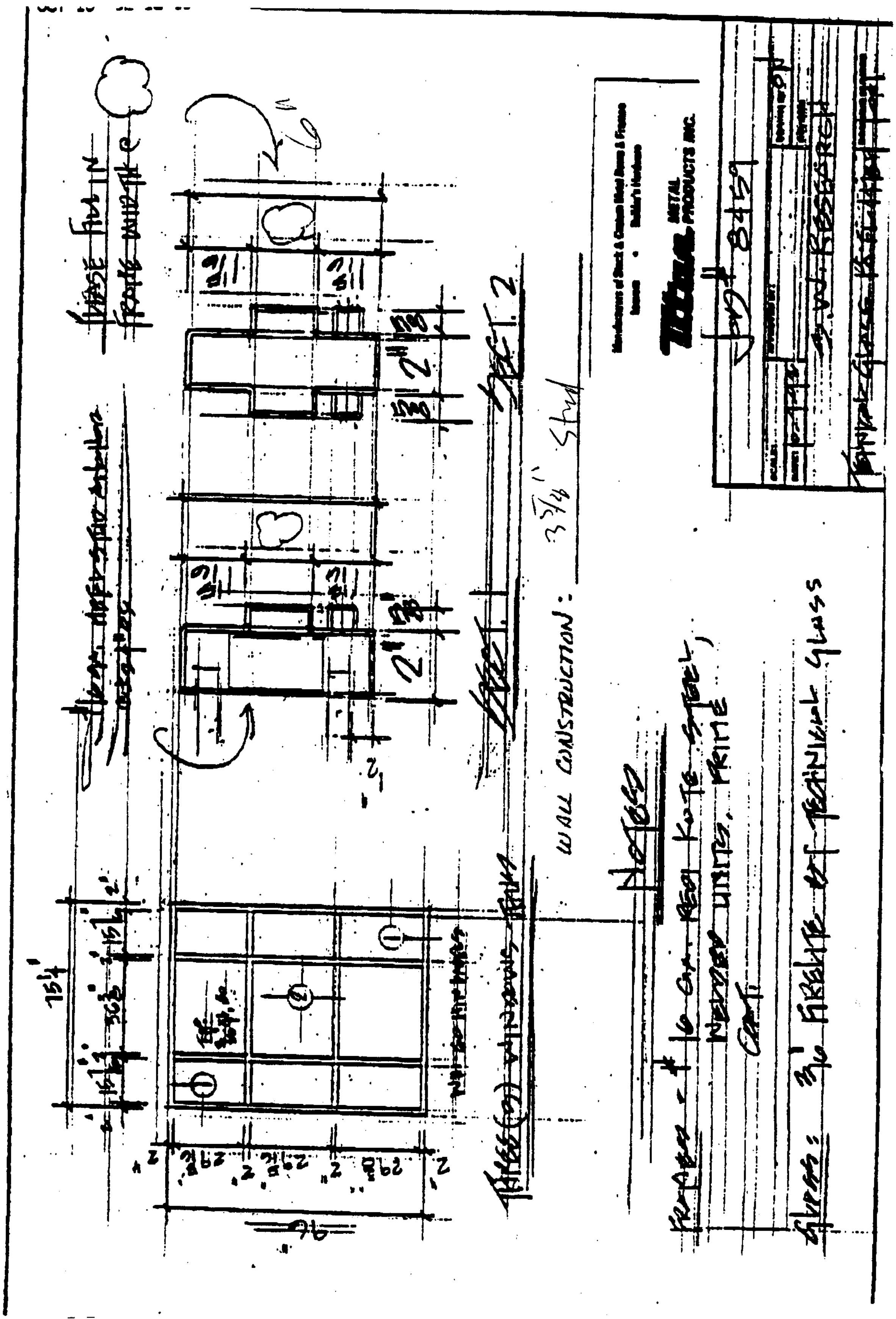



Figure A.3 Titan Metal Products Inc. Wall Construction

# APPENDIX B

## Heat Flux Transducer Calibration Information

| HFT No. | Type | Model No. | Serial No. | Location During Use | Pre-Test Calibration Sensitivity mV | at W/cm$^2$ |
|---|---|---|---|---|---|---|
| 1 | 30°THF | 64-1-18K/VRW-30 | 74047 | top of bulkhead | 9.61 | 17 |
| 2 | 30°THF | 64-1-18K/VRW-30 | 74048 | middle of bulkhead | 9.71 | 17 |
| 3 | 60°THF | 64-5SB-18K/NW-1C-60 | 78802 | middle of bulkhead | 8.60 | 17 |
| 4 | 60°RHF | 64-5SB-18K/SW-1C-60 | 78801 | middle of bulkhead | 9.45 | 17 |
| 5 | 30°THF | 64-1-18K/VRW-30 | 74049 | bottom of bulkhead | 8.45 | 17 |

AS RECEIVED CALIBRATION

CALIBRATION PER MEDTHERM PROCEDURE No. PI-20, APPENDIX 1

# CERTIFICATE OF CALIBRATION

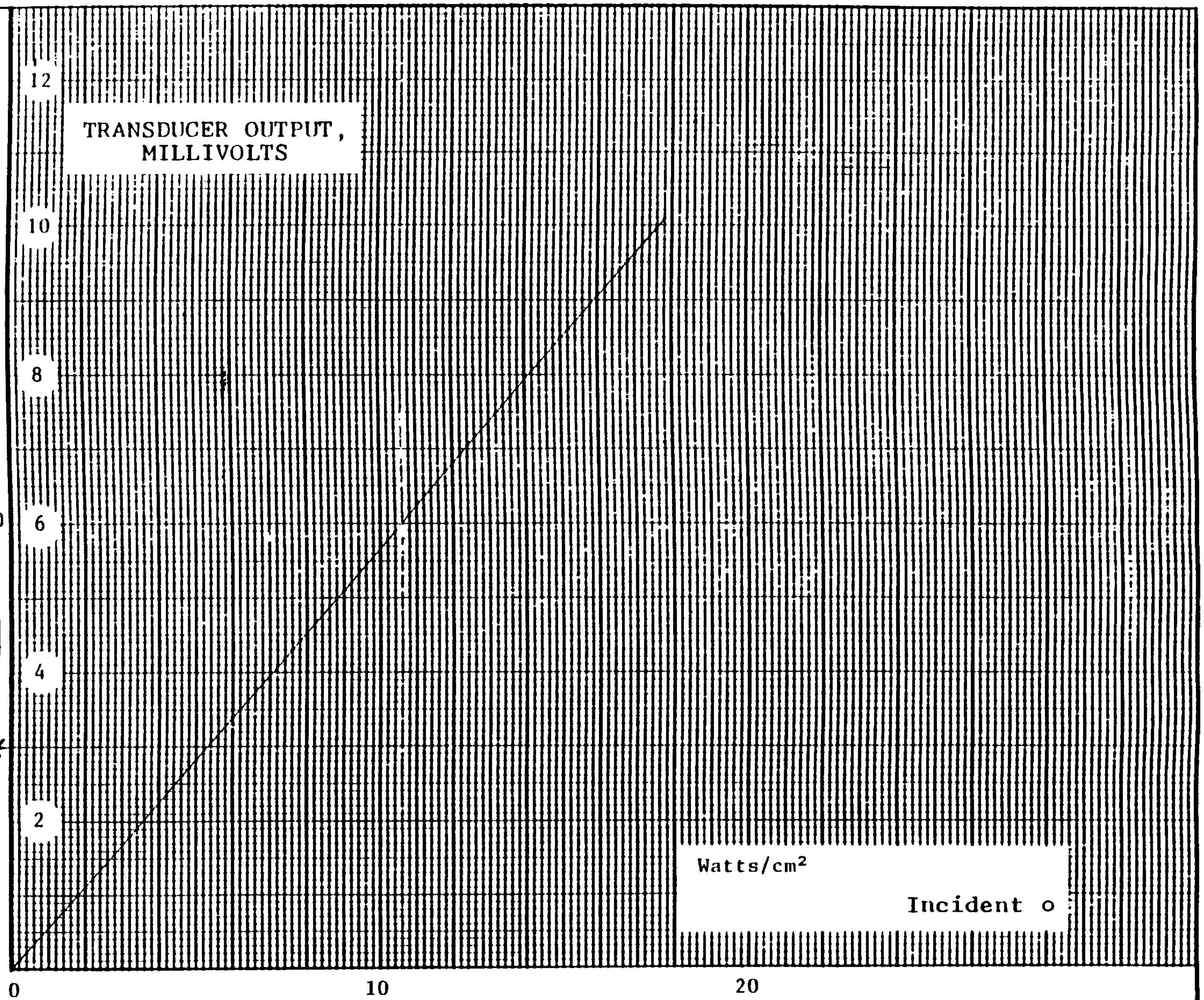
DATE 12/21/92
CUSTOMER Southwest Res.
CUSTOMER P.O. 56536

MODEL NO. 64-1-18K/VRW-30
SERIAL NO. 74047
ABSORPTIVITY 0.97
WINDOW TYPE None
SENSOR - SCHMIDT-BOELTER
REFERENCE STANDARD 238420
TESTED BY FB
QC ACCEPTANCE TEST ACCEPT MEDTHERM INSPECT NO. 2

CERTIFIED CALIBRATION
SUBSCRIBED AND SWORN TO BEFORE ME THIS 21st DAY OF Dec. 19 92

Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE




9.61mv at 17 Watts/cm²

HEAT FLUX


MEDTHERM CORPORATION POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE (205) 837-2000

AS RECEIVED CALIBRATION

CALIBRATION PER MEDTHERM PROCEDURE No. PI-20, APPENDIX 1

# CERTIFICATE OF CALIBRATION

DATE 12/21/92
CUSTOMER Southwest Res.
CUSTOMER P.O. 56536

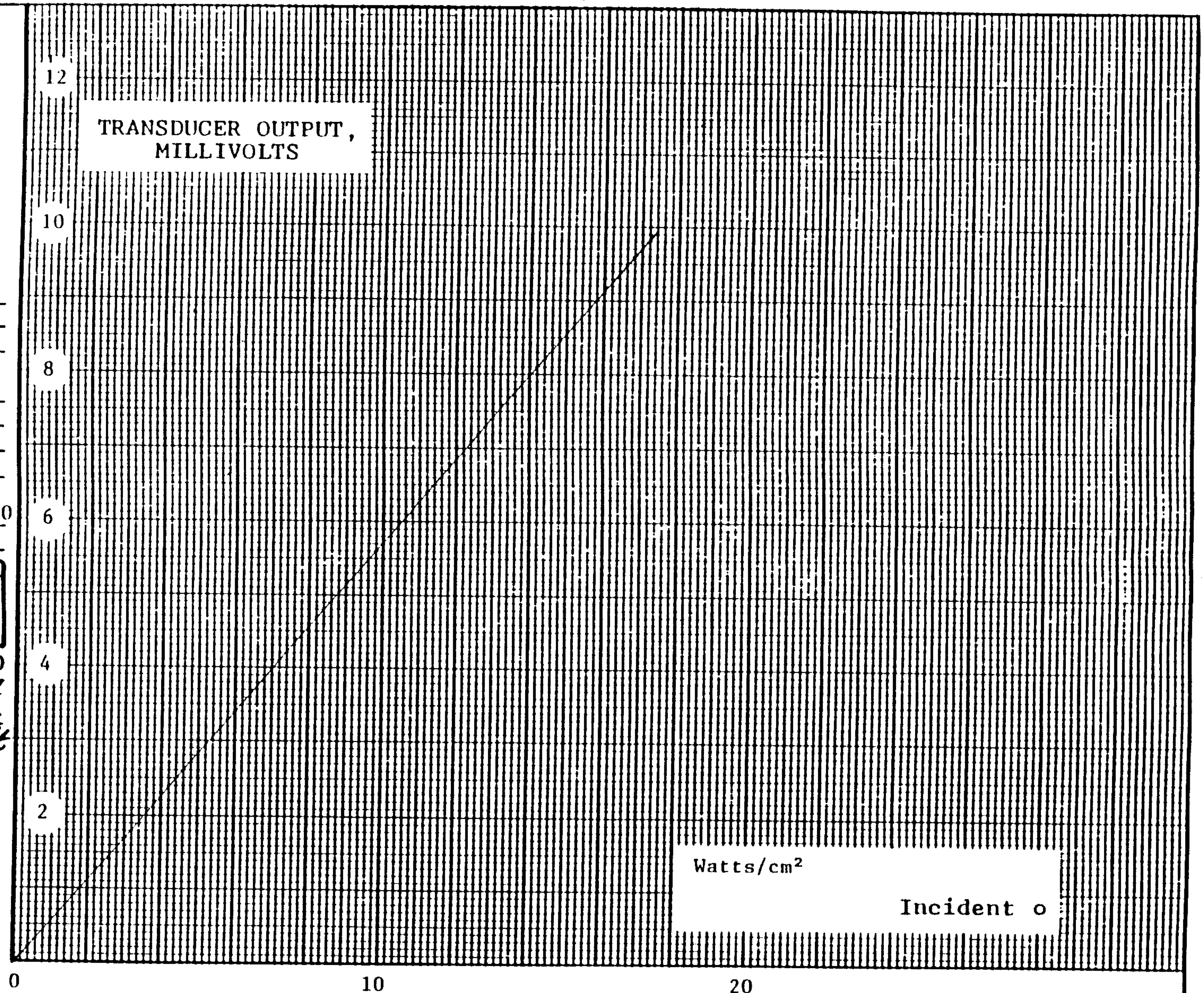
MODEL NO. 64-1-18K/VRW-30
SERIAL NO. 74048
ABSORPTIVITY 0.97
WINDOW TYPE None
SENSOR - SCHMIDT-BOELTER
REFERENCE STANDARD 238420
TESTED BY FB
QC ACCEPTANCE TEST ACCEPT

MEDTHERM INSPECT NO. 2

CERTIFIED CALIBRATION
SUBSCRIBED AND SWORN TO
BEFORE ME THIS 21st DAY
OF Dec. 19 92

Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE




9.71mv at 17 Watts/cm²

HEAT FLUX


MEDTHERM CORPORATION
POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE (205) 837-2000

# CERTIFICATE OF CALIBRATION

DATE 12/21/92
CUSTOMER Southwest Res.
CUSTOMER P.O. 56535

MODEL NO. 64-5SB-18K
SERIAL NO. 78802
ABSORPTIVITY 0.96
WINDOW TYPE None
SENSOR - SCHMIDT-BOELTER
REFERENCE STANDARD 325732
TESTED BY FB
QC ACCEPTANCE

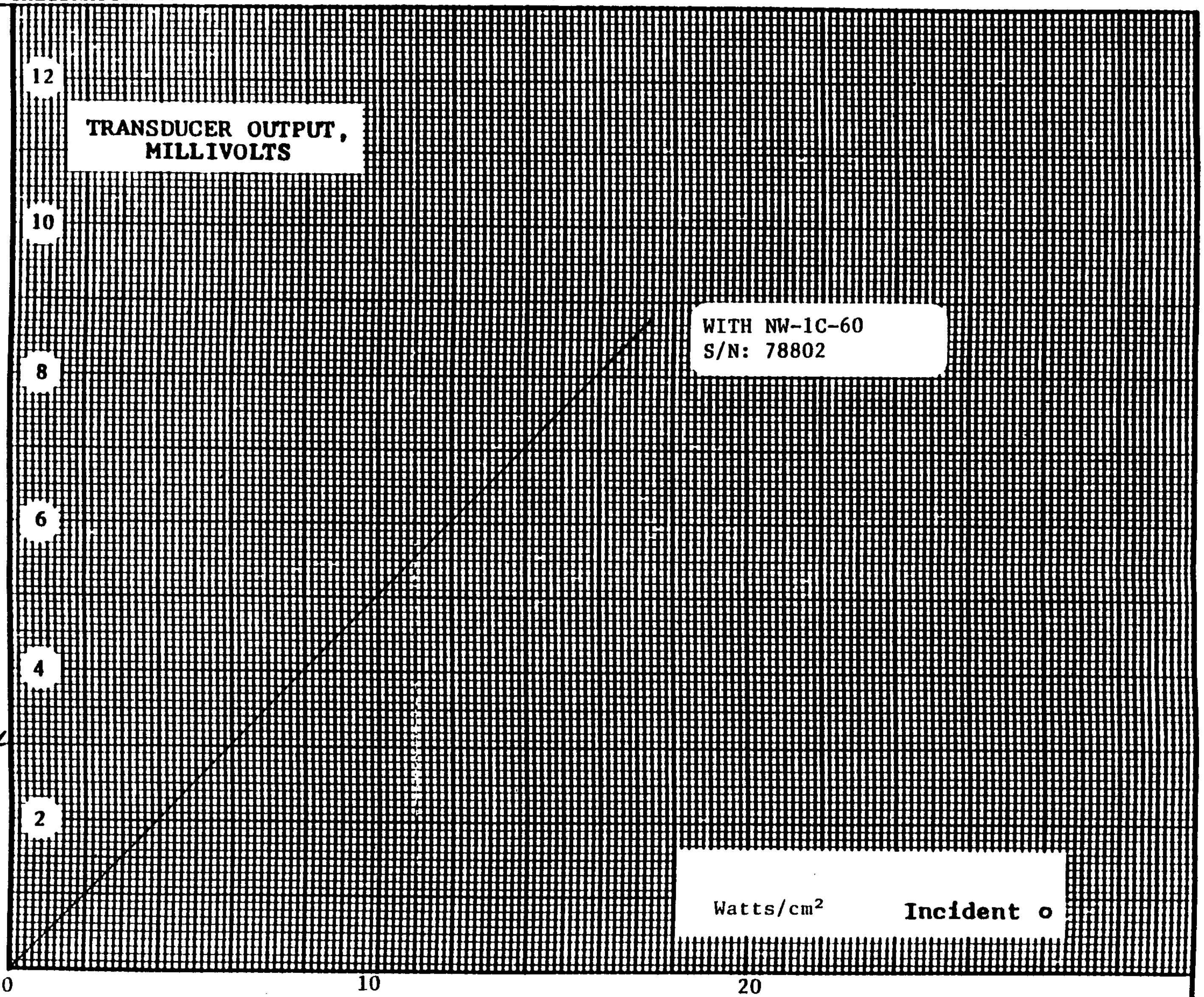
MEDTHERM INSPECT NO. 2 TEST ACCEPT

CERTIFIED CALIBRATION
SUBSCRIBED AND SWORN TO BEFORE ME THIS 21st DAY OF Dec. 1992

Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE

CALIBRATION PER MEDTHERM PROCEDURE No. PI-20, APPENDIX 1




8.60mv at 17 Watts/cm²

HEAT FLUX

MEDTHERM CORPORATION — POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE (205) 837-2000

# CERTIFICATE OF CALIBRATION

DATE 12/21/92
CUSTOMER Southwest Res.
CUSTOMER P.O. 56535

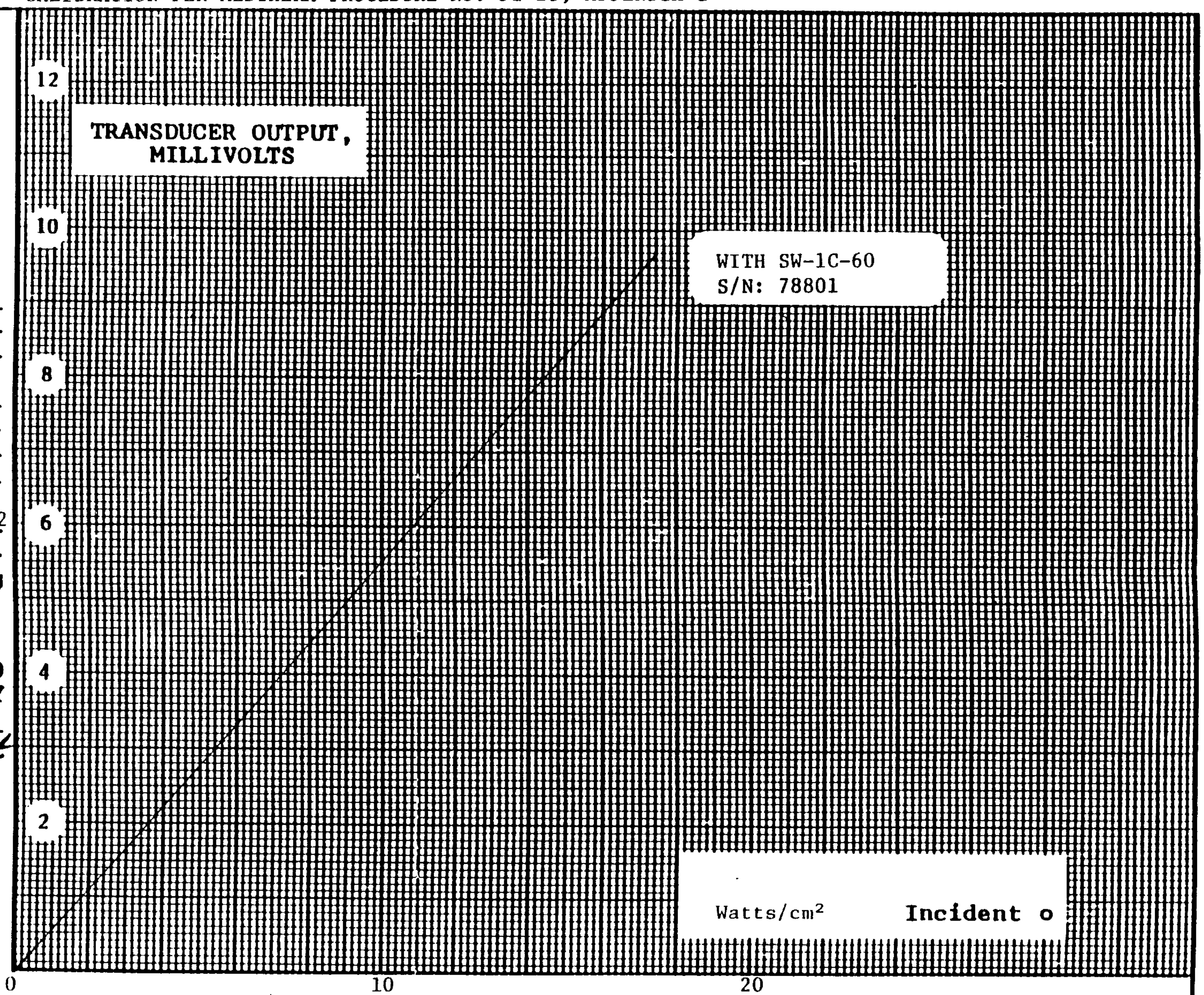
MODEL NO. 64-5SB-18K
SERIAL NO. 78801
ABSORPTIVITY 0.96
WINDOW TYPE Sapphire
SENSOR - SCHMIDT-BOELTER
REFERENCE STANDARD 325732
TESTED BY FB
QC ACCEPTANCE MEDTHERM INSPECT NO. 2 TEST ACCEPT

CERTIFIED CALIBRATION
SUBSCRIBED AND SWORN TO
BEFORE ME THIS 21st DAY
OF Dec. 1992

Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE

CALIBRATION PER MEDTHERM PROCEDURE No. PI-20, APPENDIX 1




9.45mv at 17 Watts/cm²

HEAT FLUX


**MEDTHERM CORPORATION**

POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE (205) 837-2000

AS RECEIVED CALIBRATION

CALIBRATION PER MEDTHERM PROCEDURE No. PI-20, APPENDIX 1

# CERTIFICATE OF CALIBRATION

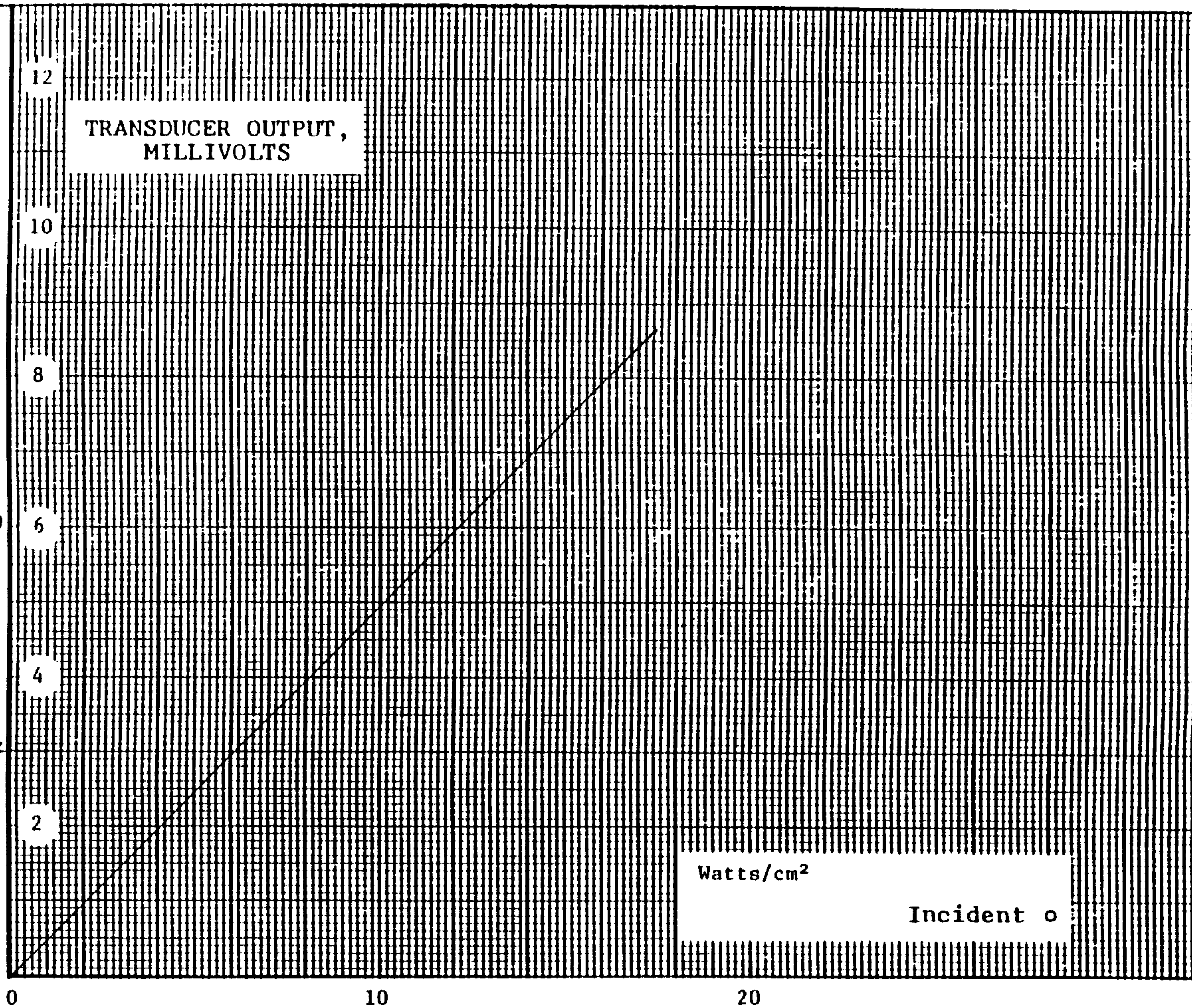
DATE 12/21/92
CUSTOMER Southwest Res.
CUSTOMER P.O. 56536

MODEL NO. 64-1-18K/VRW-30
SERIAL NO. 74049
ABSORPTIVITY 0.97
WINDOW TYPE None
SENSOR - SCHMIDT-BOELTER
REFERENCE STANDARD 238420
TESTED BY FB
QC ACCEPTANCE TEST ACCEPT MEDTHERM INSPECT NO. 2

CERTIFIED CALIBRATION
SUBSCRIBED AND SWORN TO BEFORE ME THIS 21st DAY OF Dec. 19 92

Glenda Conner
Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE




8.45mv at 17 Watts/cm²

HEAT FLUX

MEDTHERM CORPORATION

POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA

# APPENDIX C

## Photographic Documentation


Figure C.1  View of Unexposed Face During Installation of Panes and Glass Stop

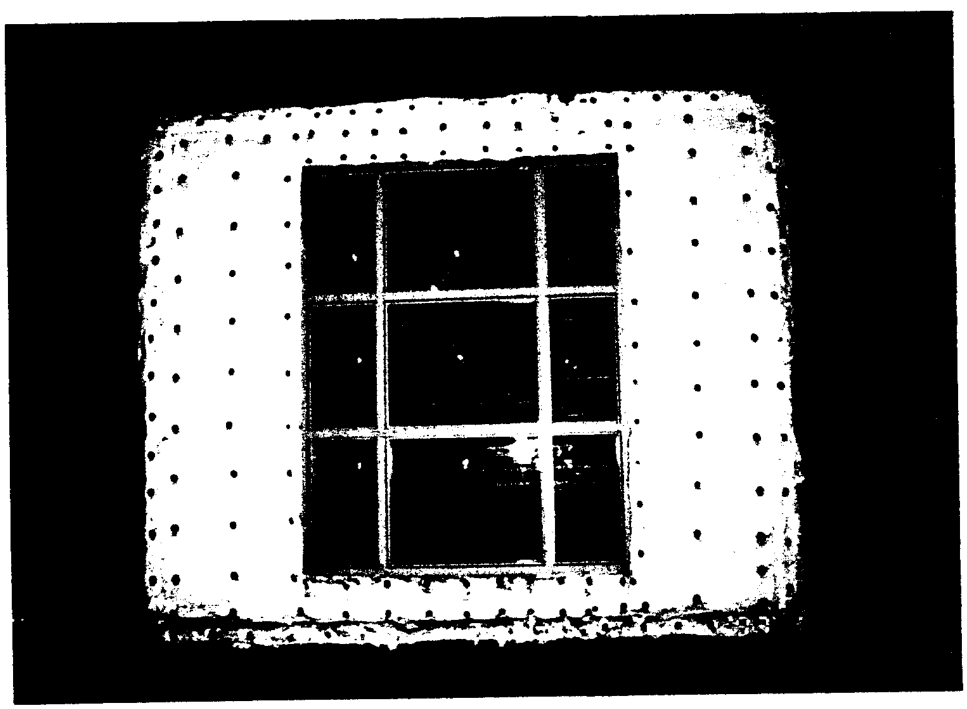


Figure C.2  View of Exposed Face of First Assembly Ready for Test; Surface Thermocouple Locations are Visible

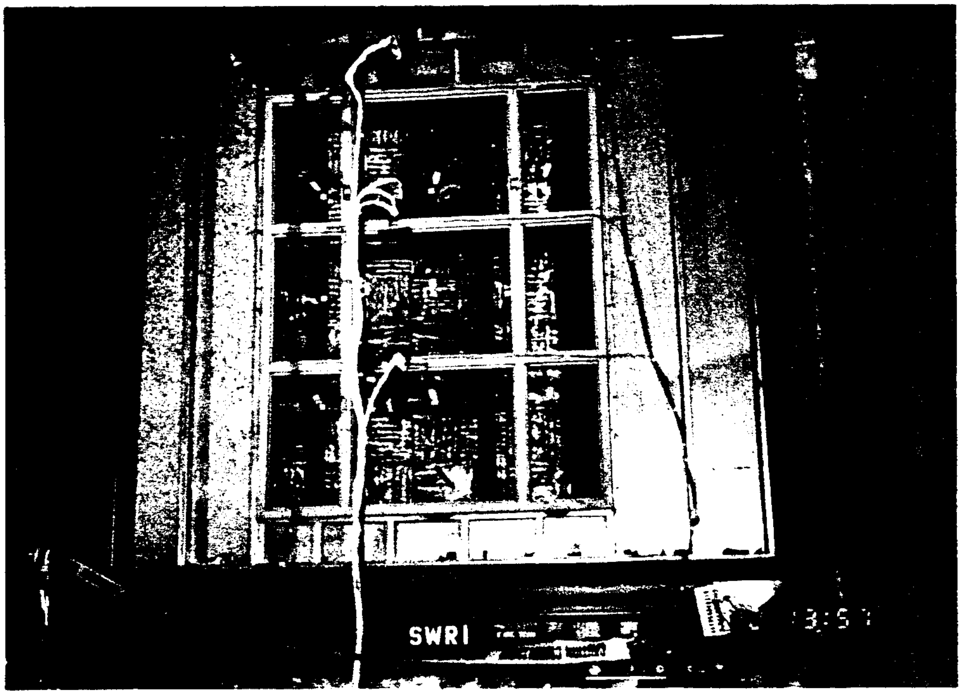



Figure C.3 Unexposed Face of First Assembly at Beginning of Test 1; Thermocouple and Heat Flux Transducer Locations are Visible

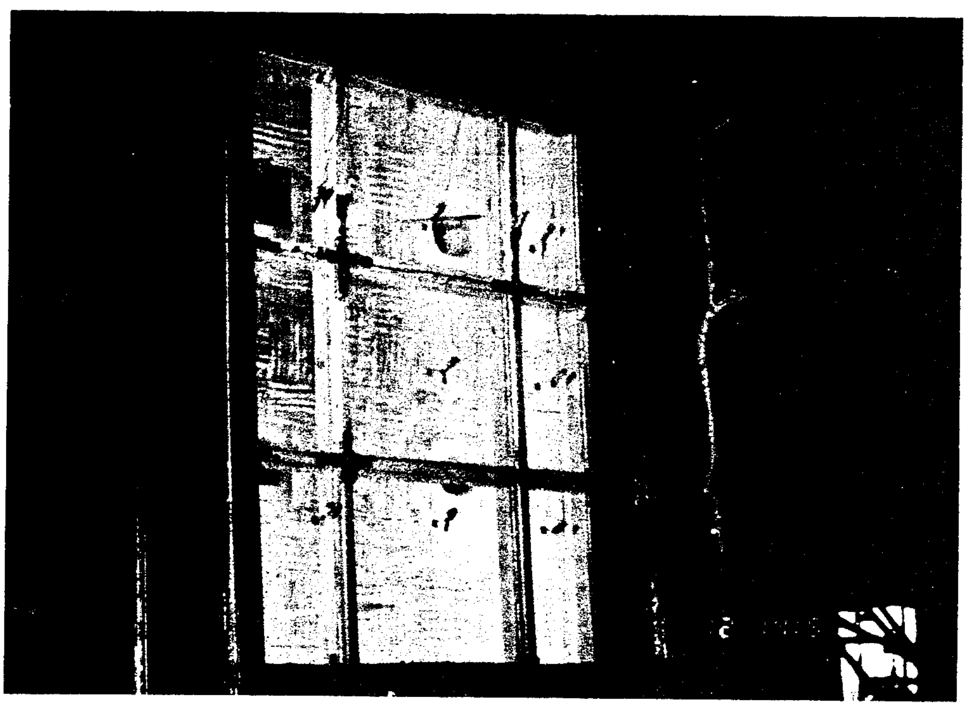


Figure C.4 View of Unexposed Face of First Assembly Near End of 60-Minute Exposure

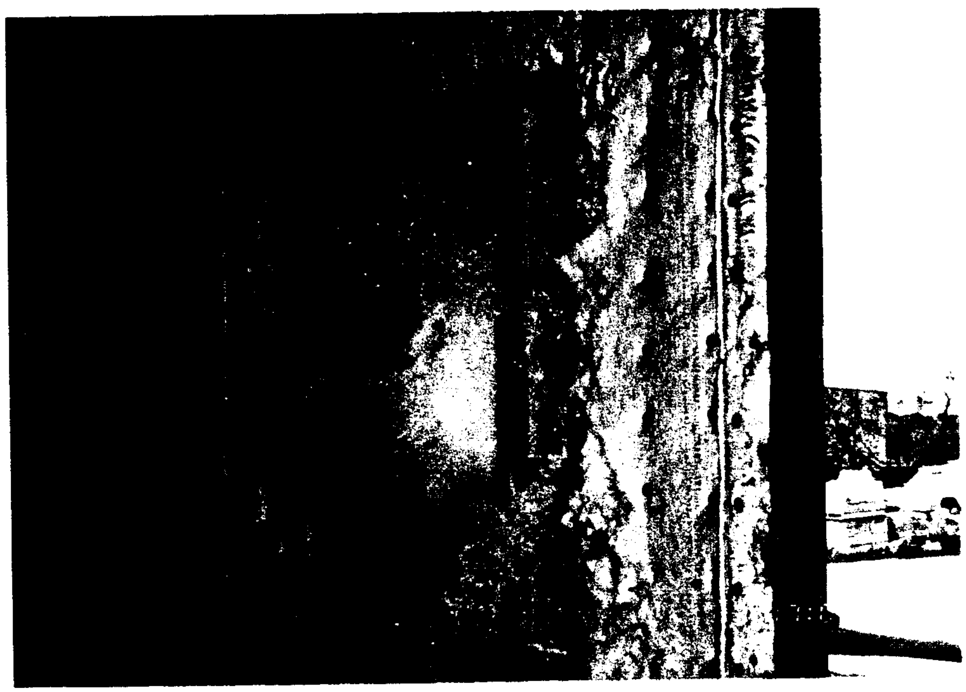


Figure C.5 View of Exposed Face of Third Assembly During Hose Stream Test

# APPENDIX D

## Temperature, Heat Flux and Pressure Data

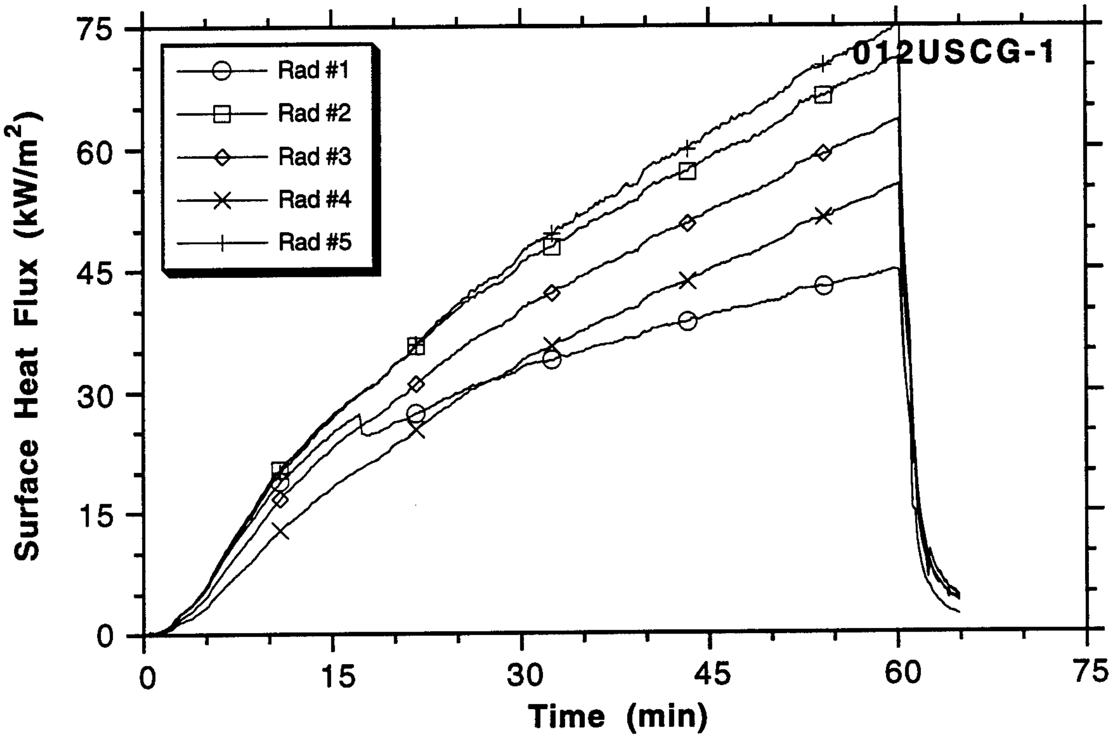


Figure D.1 Test 1 - Surface Heat Flux

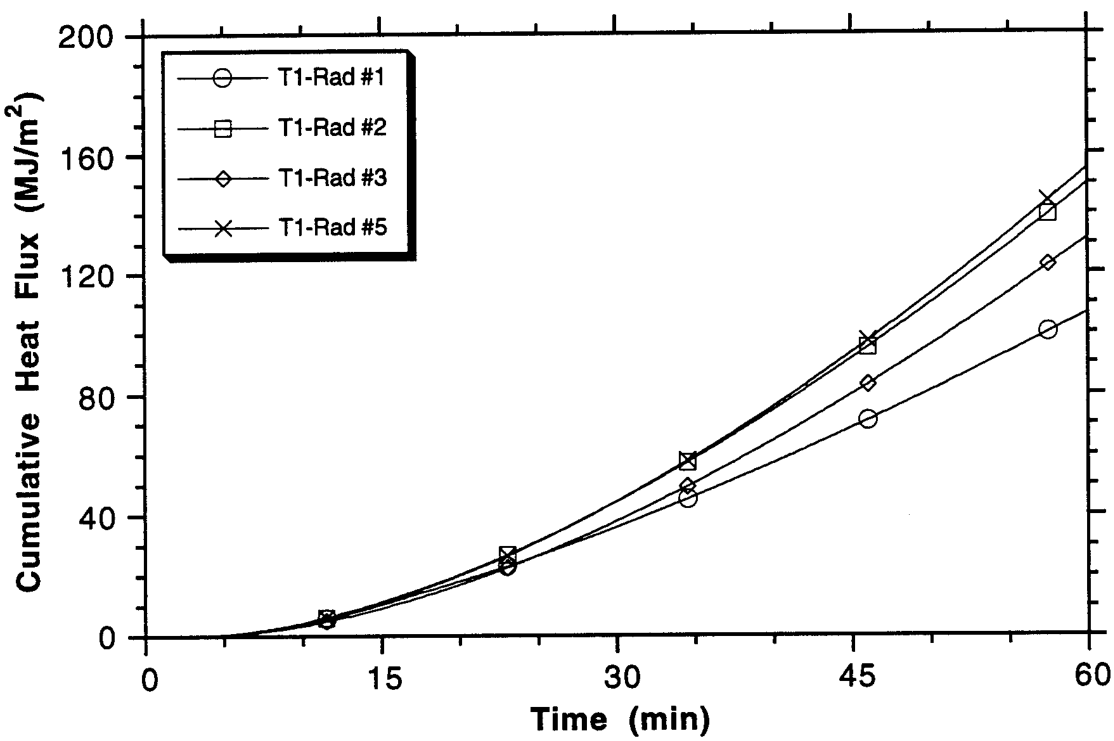


Figure D.2 Test 1 - Cumulative Surface Heat Flux

Client: US Coast Guard
Date: 12 Jan 1993
SwRI Proj. No.: 01-5306

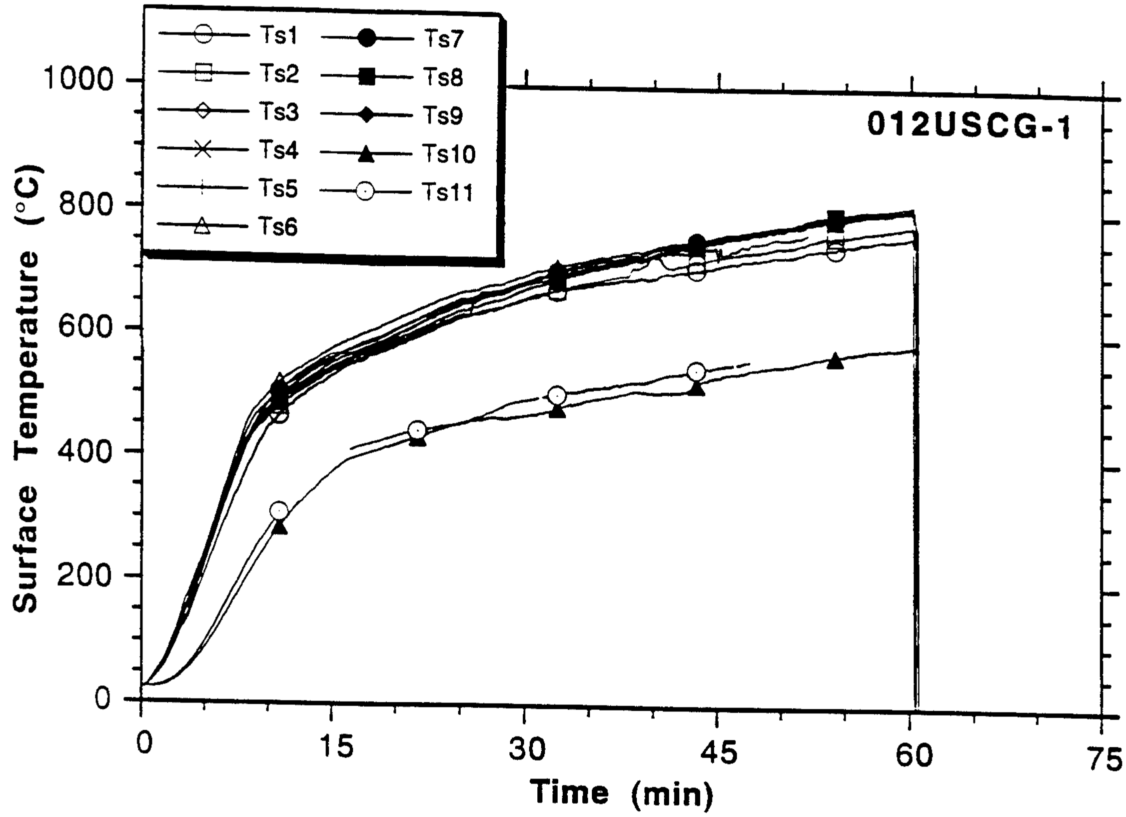



Figure D.3 Test 1 - Surface Temperatures

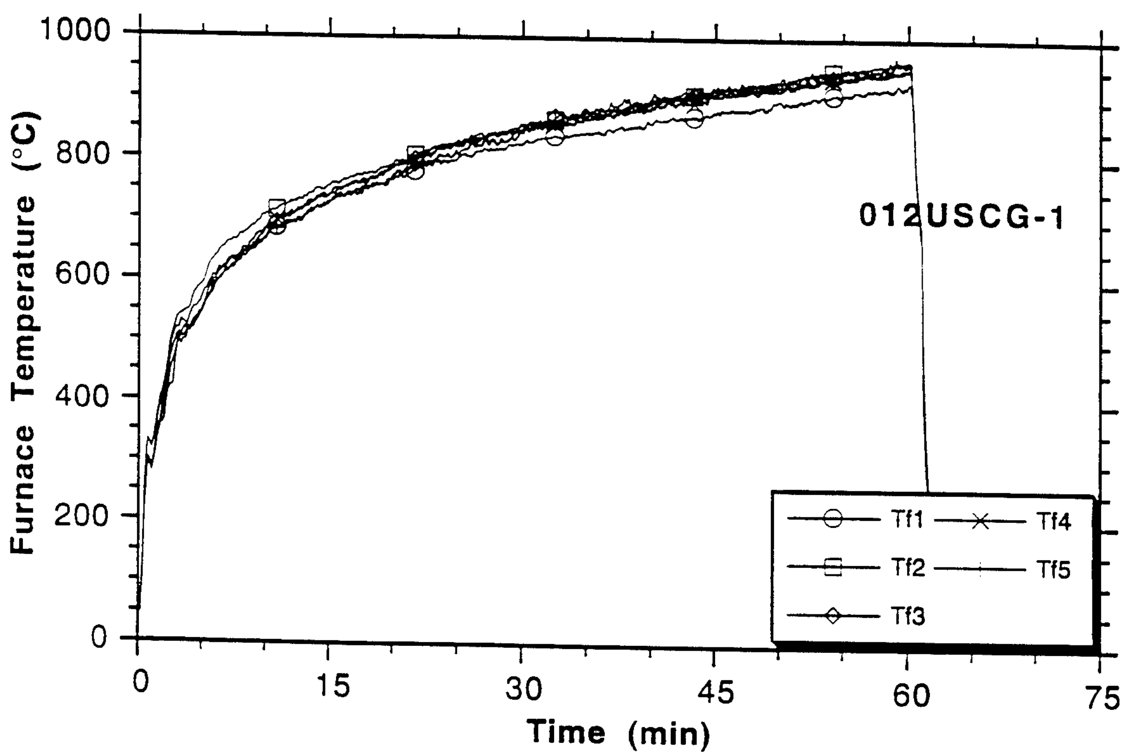



Figure D.4 Test 1 - Furnace Temperatures

Client: US Coast Guard
Date: 12 Jan 1993
SwRI Proj. No.: 01-5306

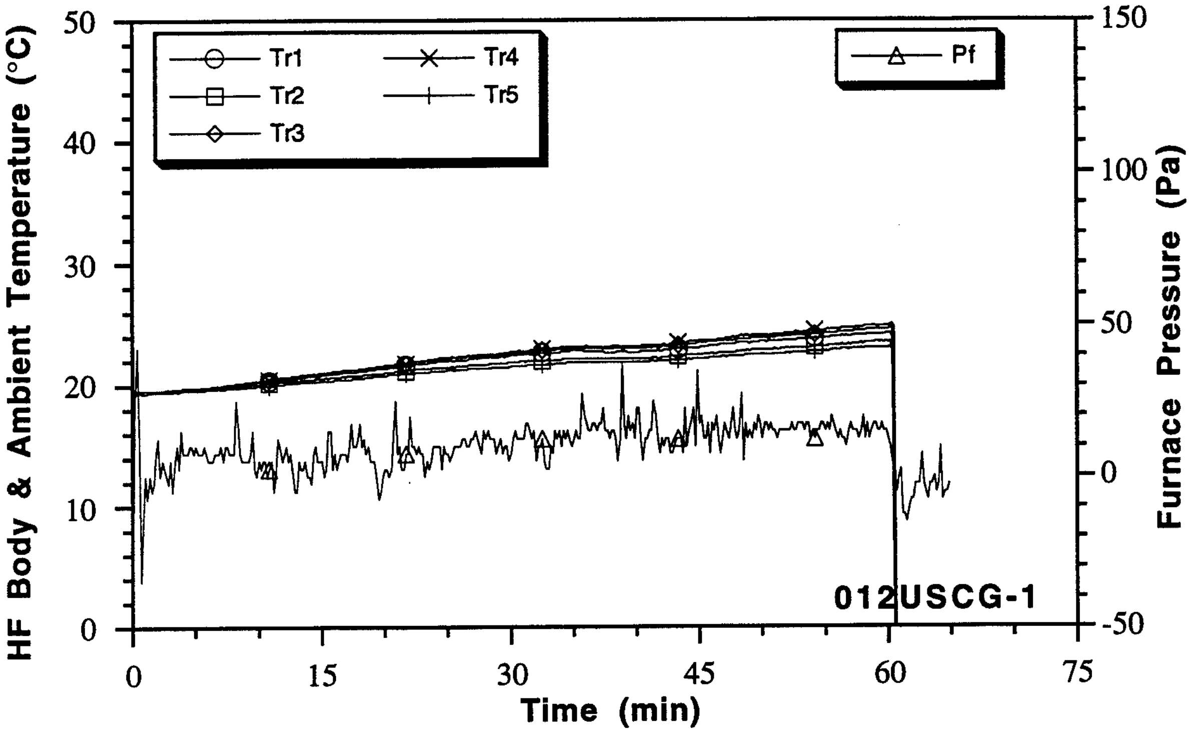



Figure D.5 Test 1 - HF Body Temperatures and Furnace Pressure

| | |
|---|---|
| Client: | US Coast Guard |
| Date: | 12 Jan 1993 |
| SwRI Proj. No.: | 01-5306 |

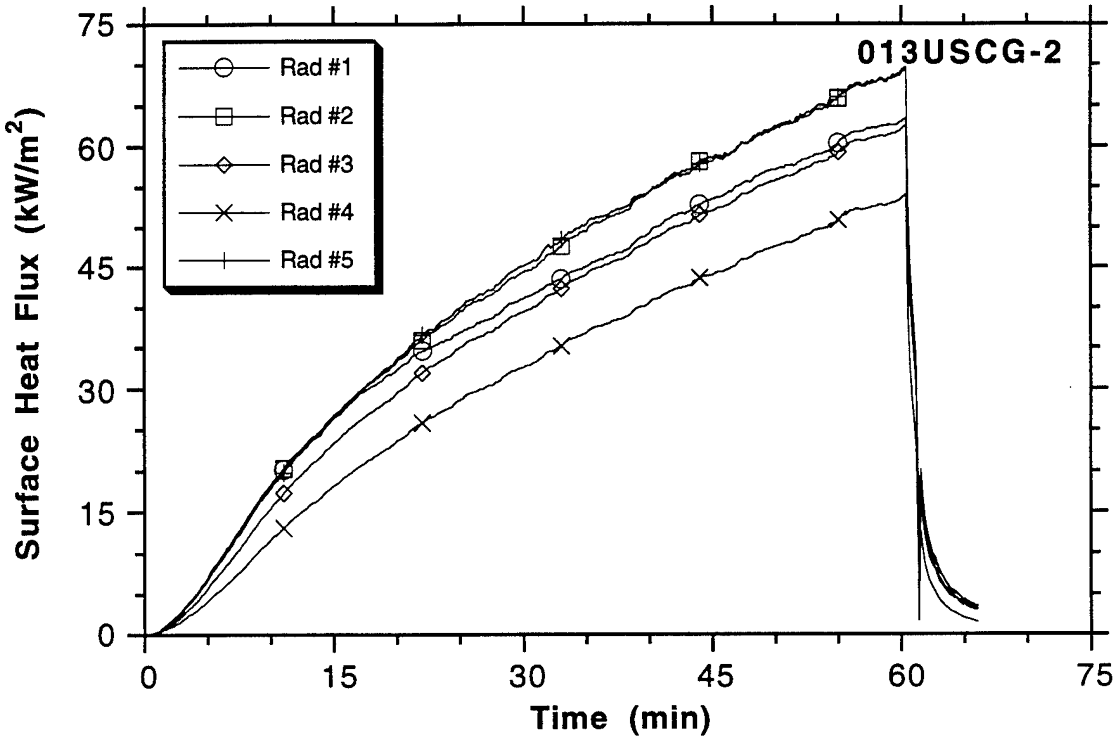



Figure D.6 Test 2 - Surface Heat Flux

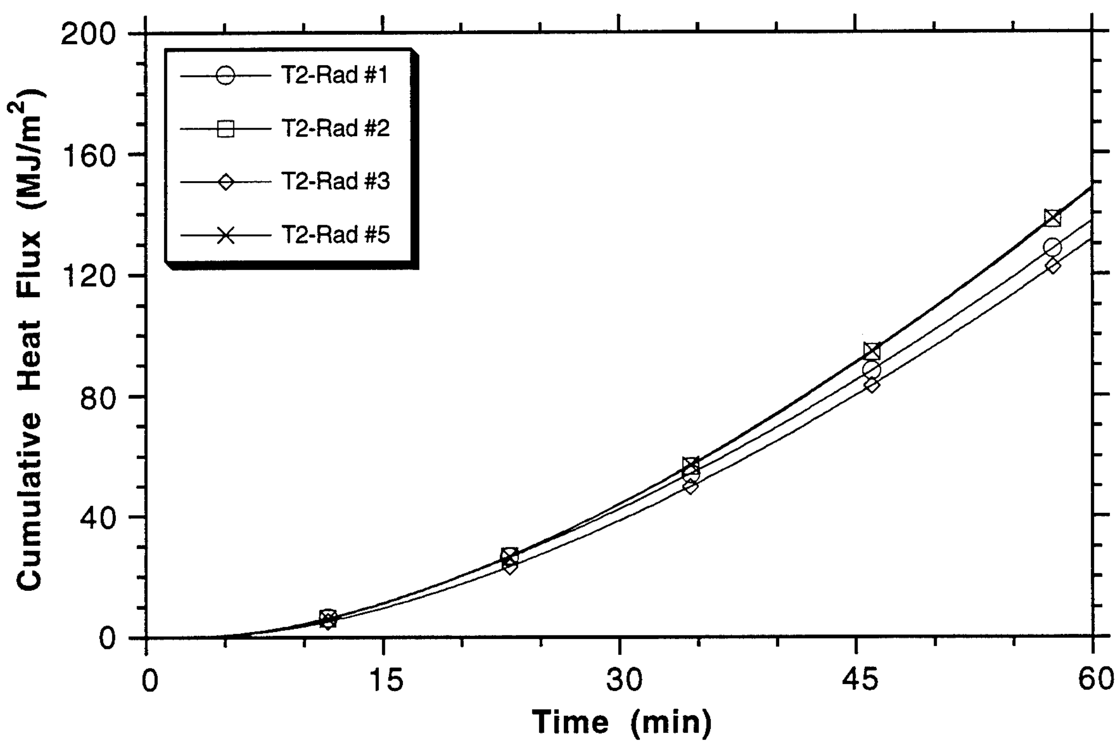



Figure D.7 Test 2 - Cumulative Surface Heat Flux

Client: US Coast Guard
Date: 13 Jan 1993
SwRI Proj. No.: 01-5306

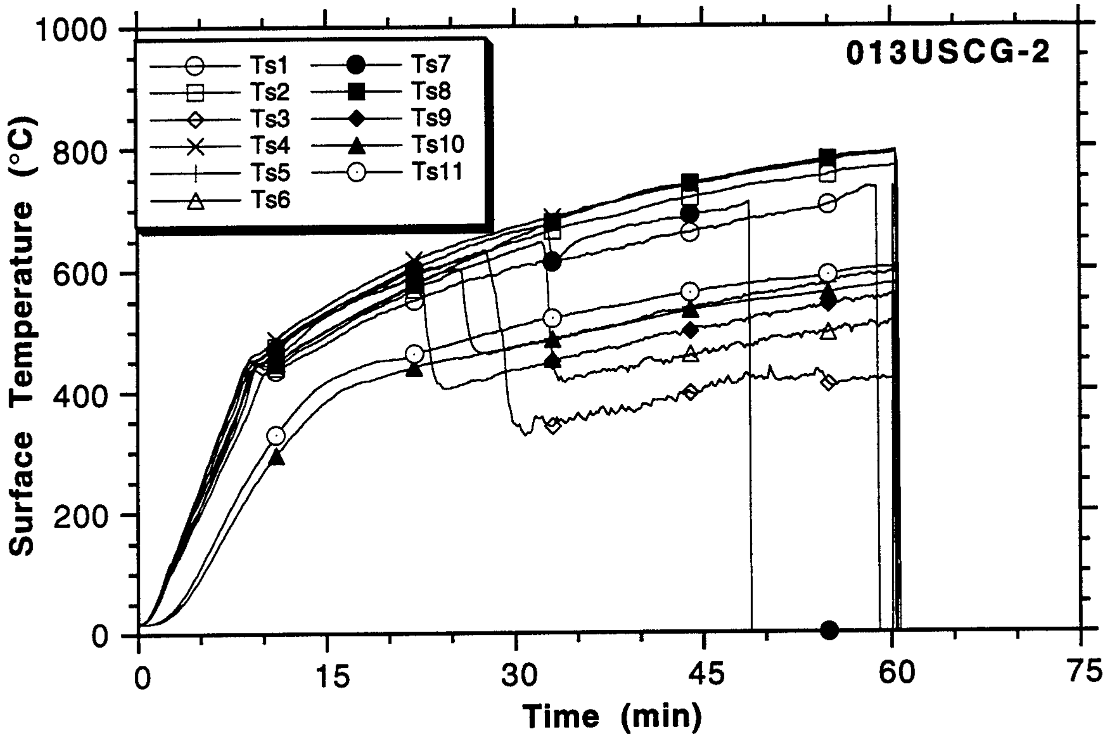



Figure D.8 Test 2 - Surface Temperatures

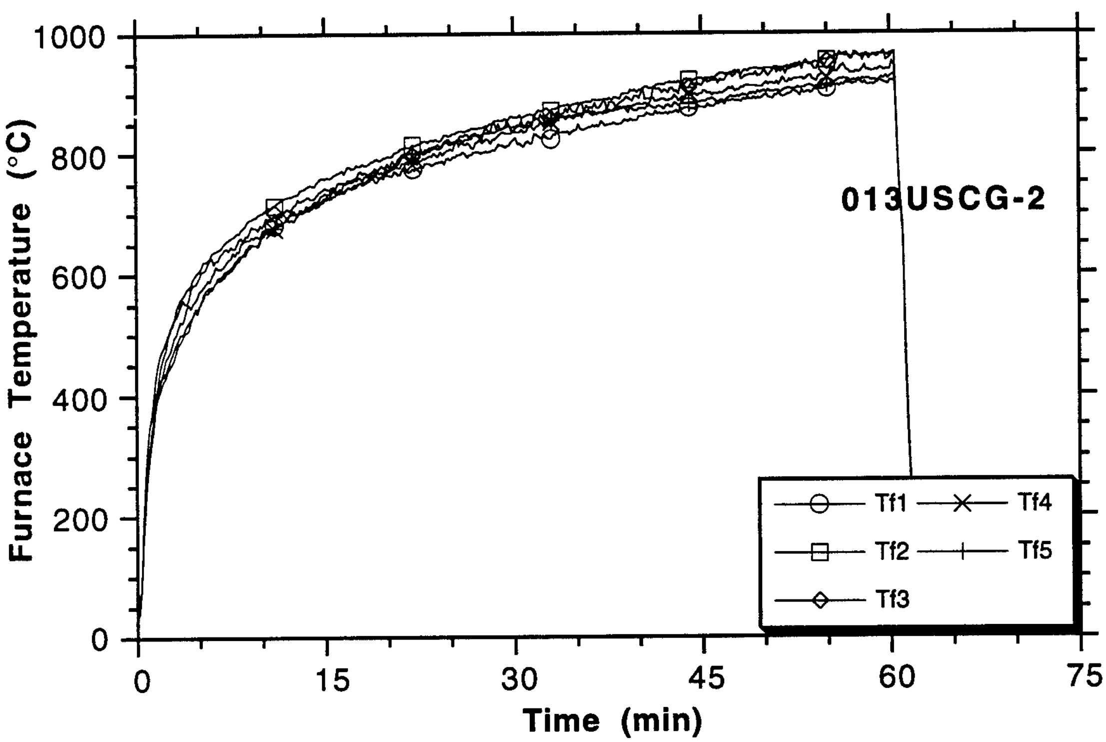



Figure D.9 Test 2 - Furnace Temperatures

Client: US Coast Guard
Date: 13 Jan 1993
SwRI Proj. No.: 01-5306

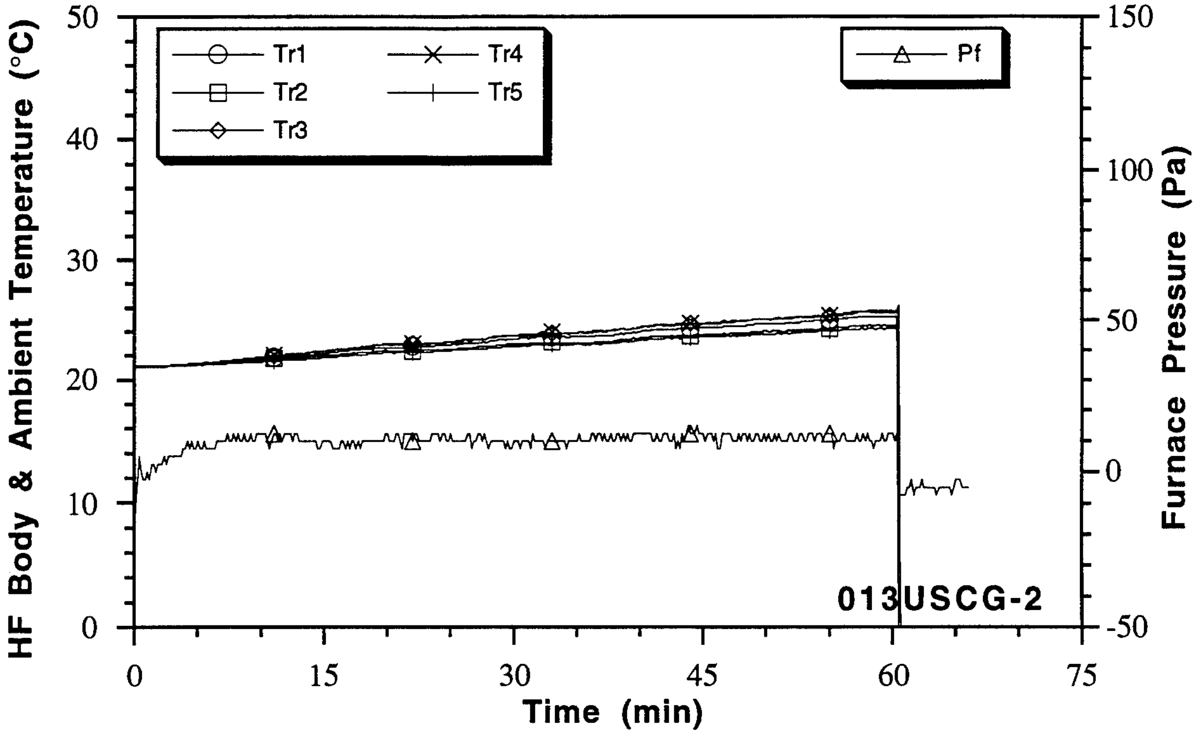



Figure D.10 Test 2 - HF Body Temperatures and Furnace Pressure

Client: US Coast Guard
Date: 13 Jan 1993
SwRI Proj. No.: 01-5306

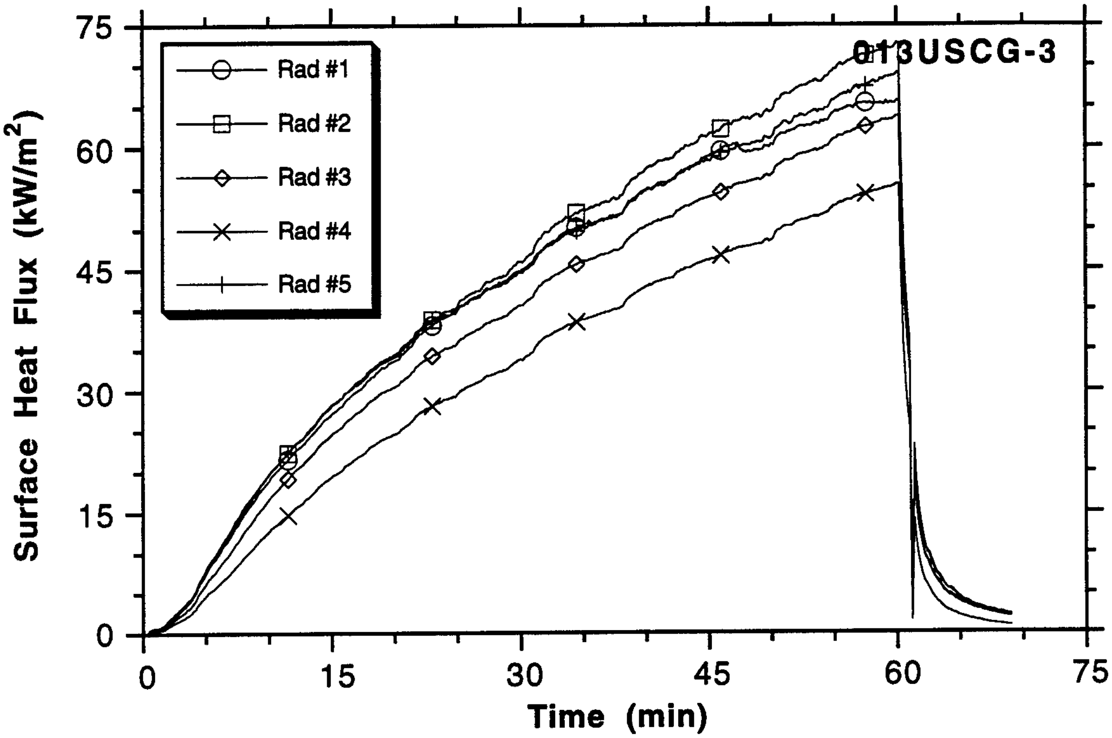



Figure D.11 Test 3 - Surface Heat Flux

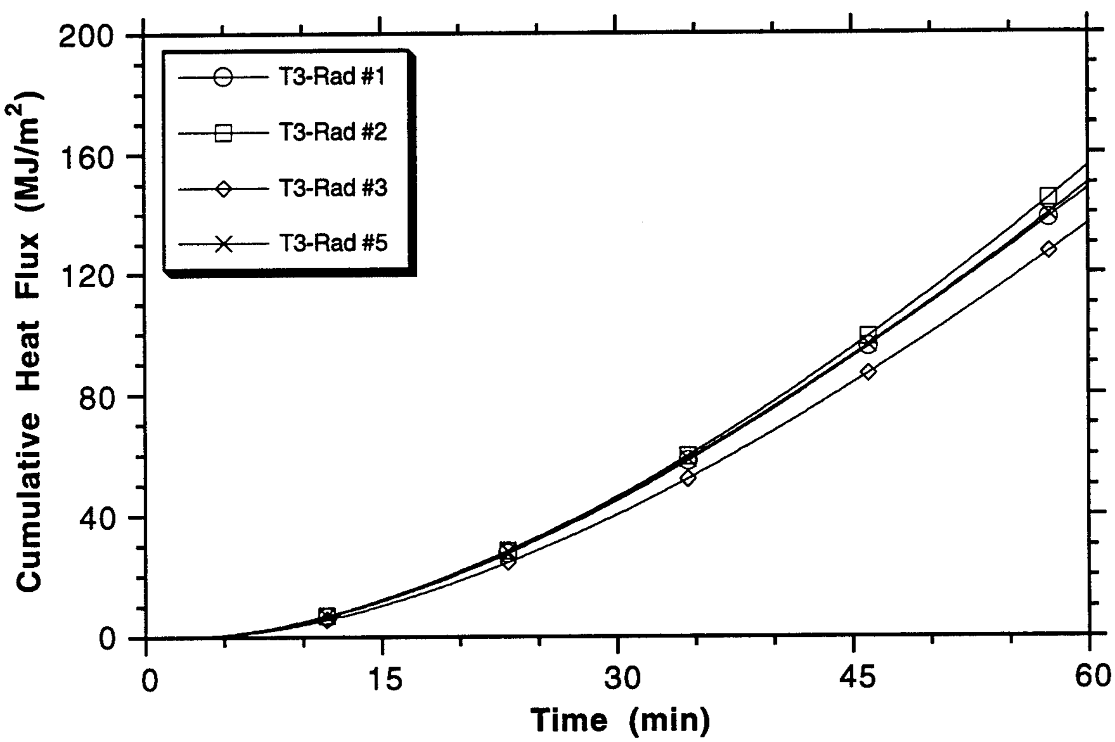



Figure D.12 Test 3 - Cumulative Surface Heat Flux

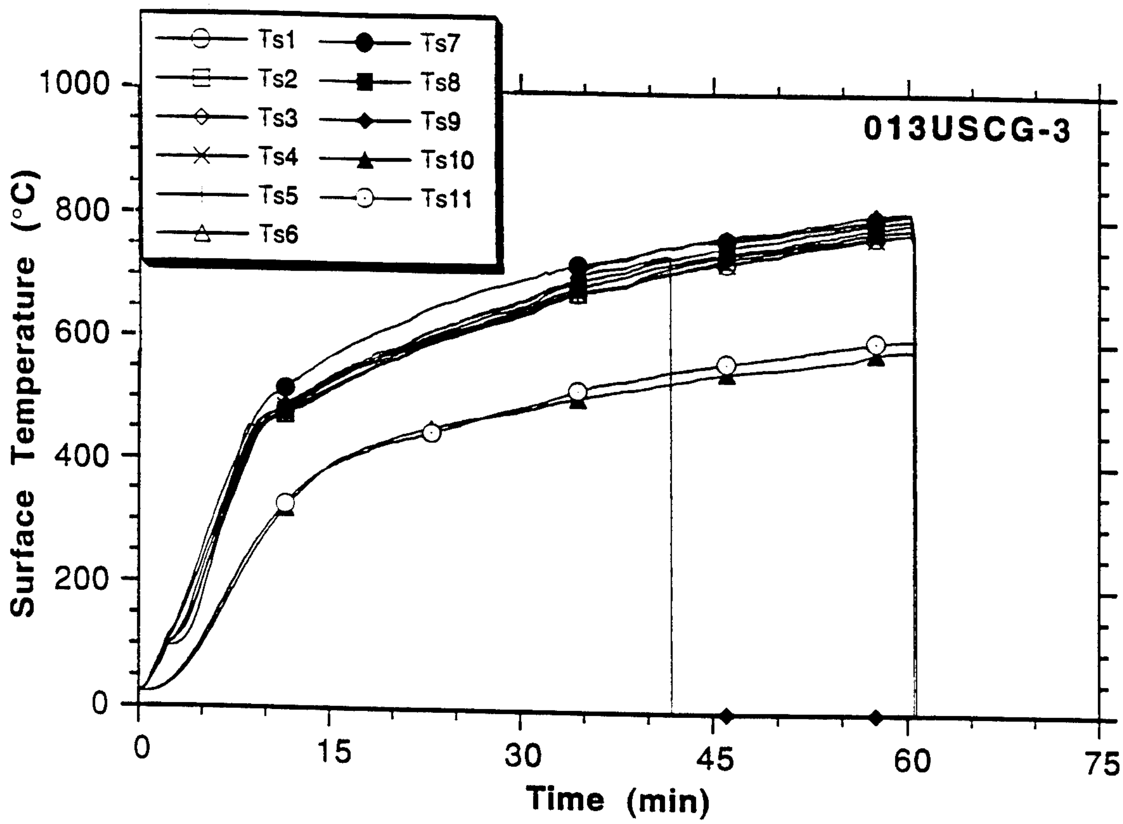



Figure D.13 Test 3 - Surface Temperatures

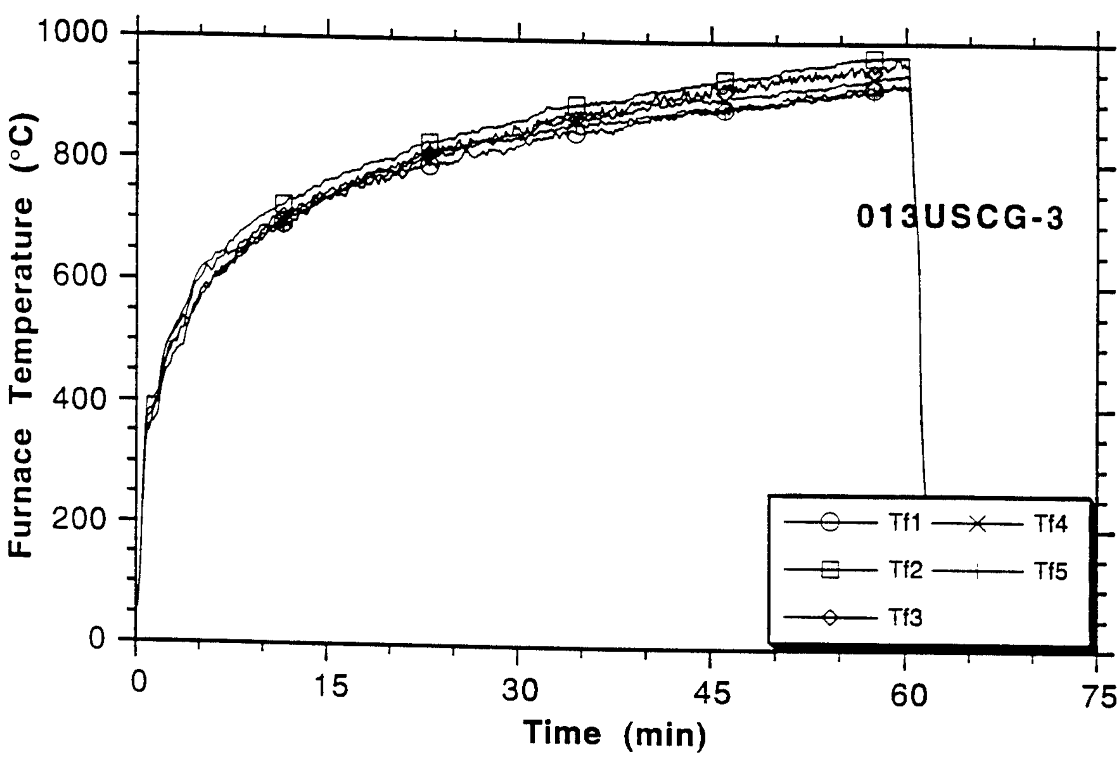



Figure D.14 Test 3 - Furnace Temperatures

Client: US Coast Guard
Date: 13 Jan 1993
SwRI Proj. No.: 01-5306

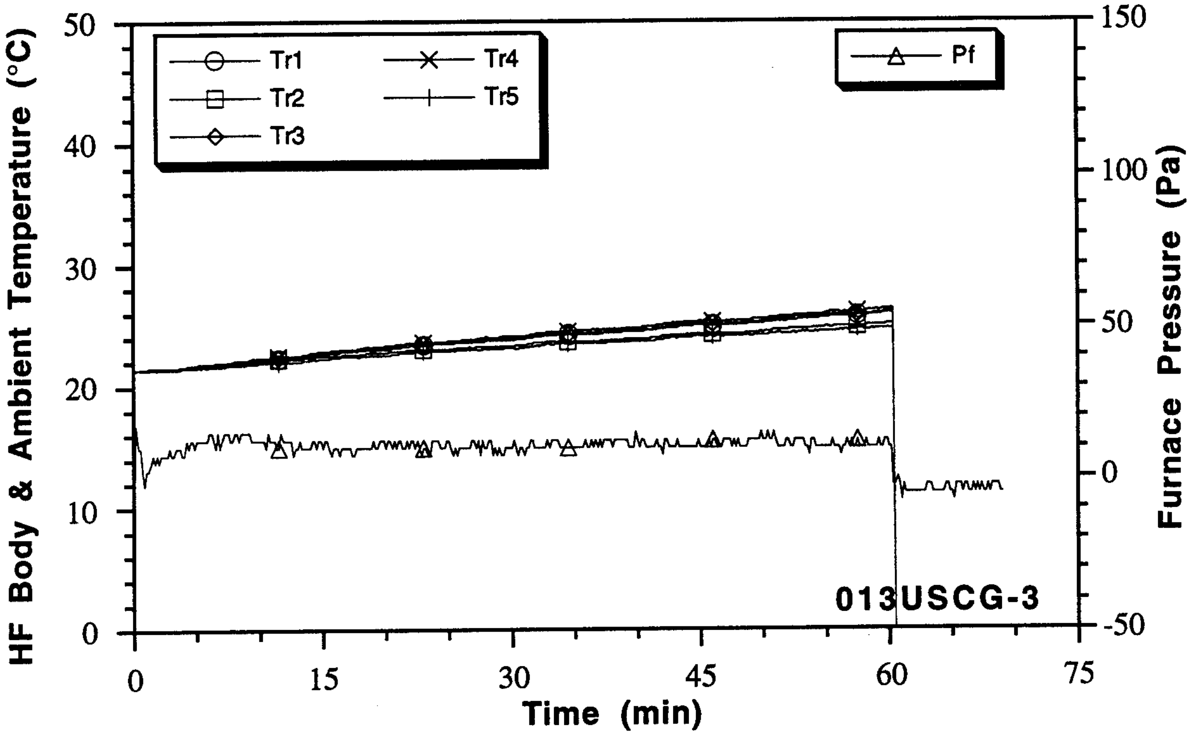



Figure D.15 Test 3 - HF Body Temperatures and Furnace Pressure

Client: US Coast Guard
Date: 13 Jan 1993
SwRI Proj. No.: 01-5306